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Geothermal Energy: Economic Potential of Three Sites in Alaska

UNITED STATES DEPARTMENT OF THE INTERIOR

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Geothermal Energy: Economic Potential of Three Sites in Alaska

By Jimmie C. Rosenbruch and Robert G. Bottge
Alaska Field Operation Center, Juneau, Alaska

UNITED STATES DEPARTMENT OF THE INTERIOR
Thomas S. Kleppe, Secretary

Jack W. Carlson, Assistant Secretary—Energy and Minerals

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CONTENTS

	Page
Abstract	1
Introduction	1
Acknowledgments	2
Background	2
Geothermal sources in Alaska	2
North district	3
East-central and west-central districts	4
Southwest district	4
South-central district	4
Southeast district	5
Geothermal Steam Act of 1970	5
Potential for development	6
Power applications	8
Power applications in Alaska	9
Kobuk site	10
Unalaska site	14
Stikine River site	19
Space heating applications	23
Space heating applications in Alaska	26
Agriculture applications	26
Agriculture applications in Alaska	29
Kobuk site	30
Unalaska site	32
Stikine River site	34
Conclusions	37
References	38

ILLUSTRATIONS

1. Geothermal resources of Alaska by MINFILE district.... 3
2. Index map of Alaska.... 7
3. Geothermal power-generating system.... 9
4. Vicinity map of Kobuk, Alaska.... 11
5. Vicinity map of Unalaska, Alaska.... 16
6. Vicinity map of Stikine River, Alaska.... 20
7. Space heating system, Oregon Technical Institute, Klamath Falls, Oreg.... 24
8. One of three pump sites supplying geothermal heating water to Oregon Technical Institute.... 24
9. Geothermal pump at Oregon Technical Institute.... 24
10. Water gage showing incoming geothermal water at Oregon Technical Institute.... 25
11. Holding tank for geothermal water at Oregon Technical Institute.... 25
12. Domestic hot water being heated by geothermal water at Oregon Technical Institute.... 25
13. Space heating system for residences, Klamath Falls, Oreg.... 26
14. Schematic diagram of a greenhouse heated by geothermal water, Hobo Hot Springs, Wendell, Calif.... 27

ILLUSTRATIONS--Continued

Page

15. Withdrawal of geothermal water from a natural hot spring at Wendell, Calif.. 28
16. Plant-food holding tanks and greenhouses under construction, Wendell, Calif.. 28
17. Completed greenhouse ready for planting, Wendell, Calif............. 28
18. Hot air from heat exchanger is forced through perforated plastic tube, Wendell, Calif.. 28
19. Interior of greenhouse at Wendell, Calif., showing heat-distribution system and finished product--vine-ripened tomatoes............... 28

TABLES

1. Capital cost for geothermal powerplant, Kobuk site.................. 12
2. Estimated annual cost for geothermal powerplant, Kobuk site......... 13
3. Capital cost for diesel powerplant, Kobuk site...................... 13
4. Estimated annual cost for diesel powerplant, Kobuk site............. 14
5. Comparative financial analyses, Kobuk site.......................... 14
6. Capital cost for diesel powerplant, Unalaska site................... 15
7. Estimated annual cost for diesel powerplant, Unalaska site.......... 15
8. Capital cost for geothermal powerplant, Unalska site................ 17
9. Estimated annual cost for geothermal powerplant, Unalaska site...... 18
10. Comparative financial analyses, Unalaska site....................... 18
11. Capital cost for diesel powerplant, Stikine River site.............. 19
12. Estimated annual cost for diesel powerplant, Stikine River site..... 20
13. Capital cost for geothermal powerplant, Stikine River site.......... 21
14. Estimated annual cost for geothermal powerplant, Stikine River site. 22
15. Comparative financial analyses, Stikine River site.................. 22
16. Capital costs for greenhouses, Kobuk site........................... 30
17. Estimated annual operating cost for greenhouses, Kobuk site......... 31
18. Financial analyses for greenhouses, Kobuk site...................... 32
19. Capital costs for greenhouses, Unalaska site........................ 33
20. Estimated annual operating costs for greenhouses, Unalaska site..... 33
21. Financial analyses for greenhouses, Unalaska site................... 34
22. Capital costs for greenhouses, Stikine River site................... 35
23. Estimated annual operating costs for greenhouses, Stikine River site 36
24. Financial analyses for greenhouses, Stikine River site.............. 36

GEOTHERMAL ENERGY: ECONOMIC POTENTIAL OF THREE SITES IN ALASKA

by

Jimmie C. Rosenbruch[1] and Robert G. Bottge[2]

ABSTRACT

The Federal Bureau of Mines evaluated the prospects for using geothermal energy to generate electricity for mines in remote areas. Given the development of a geothermal resource for this purpose, the subsidiary uses of space heating and agriculture were then examined to see if other industries might be viable given a cheap source of heat energy. Sites investigated were located in three areas of Alaska: Kobuk in the northwest, Unalaska in the southwest, and Stikine River in the southeast. Each site was relatively close to mineral deposits whose prospects for development would be enhanced with cheap power.

INTRODUCTION

With today's greatly accelerated costs of conventional energy forms, particularly hydrocarbons, our attention must turn to unconventional energy forms, such as nuclear, solar, wind, tide, and geothermal. This report attempts, in broad terms, to analyze the economic potential for geothermal energy development at three sites in Alaska. These sites were selected based upon all or part of the following criteria: (1) surface manifestation of geothermal activity (thermal springs as reported by the U.S. Geological Survey), (2) diverse geographical locations (each representing a typical region of Alaska), (3) existing and/or potential energy demand (based upon existing human activity and/or potential mineral development), and (4) the assumption that each geothermal site could be developed to produce sufficient energy to satisfy projected power requirements for mining and related uses. Power requirements were determined to be 2 MW, 20 MW, and 40 MW for the Unalaska, Stikine River, and Kobuk sites, respectively. Electrical generating costs were derived using standard costing techniques. It must be emphasized that the data were insufficient to guarantee that such costs could actually be attained at the selected sites.

Environmental effects were considered in a general manner. It was assumed that all brines were reinjected into the ground. The greatest unknowns lay in accurately assessing the extent and viability of geothermal

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[1]Civil engineer (now with Glacier Guides, Inc., Juneau, Alaska).
[2]Mining engineer.

reservoirs. Reservoir temperature, recharge rate, brine or fluid composition, and capacity for long-term energy production are some of the variables that must be determined for an actual installation.

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BACKGROUND

Geothermal areas exist throughout the world, primarily along the belts of young volcanism that ring the Pacific Ocean and that follow the mid-oceanic ridges (7).[3] Of the known global geothermal sources, probably 5% to 10% are in the United States (30).

Geothermal energy was first used to produce commercial electricity in Italy in 1904. It was 50 years before the United States seriously began exploring this "new" energy source. Electric production began at The Geysers, Calif., in 1960. By 1974, the United States ranked first in geothermal power production with a capacity in excess of 412 MW (4). The prospects for continued growth of geothermal power production are good since "...geothermal energy may prove to be the 'cleanest' source of power readily available to man" (10). In 1974, the estimated cost of generating electricity from dry-stream geothermal sources was 6.7 mills per kW-hr; from liquid-dominated geothermal sources, 8.0 mills; from nuclear power, 8.0 mills; from coal, 10.9 mills; from oil, 15.0 mills; and from diesel fuel for small plants (to 10 MW), 36.0 mills (14).

GEOTHERMAL SOURCES IN ALASKA

Hot springs, though widely distributed in Alaska, were only slightly utilized by the natives before the coming of the white man (28). Most of these springs occur in Alaska's southeastern and southwestern districts[4] along the Pacific Rim "ring of fire" (fig. 1). Although surface manifestations are generally not as prevalent, the U.S. Geological Survey has also identified large areas in the Wrangell Mountain district (south central), Yukon River district (east central), and Seward Peninsula district (west central) as having high geothermal energy potential (17).

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[3] Underlined numbers in parentheses refer to items in the list of references at the end of this report.

[4] The districts used in this report are the six MINFILE districts devised by the Mineral Industry Research Laboratory for computerizing mineral claim data (9).

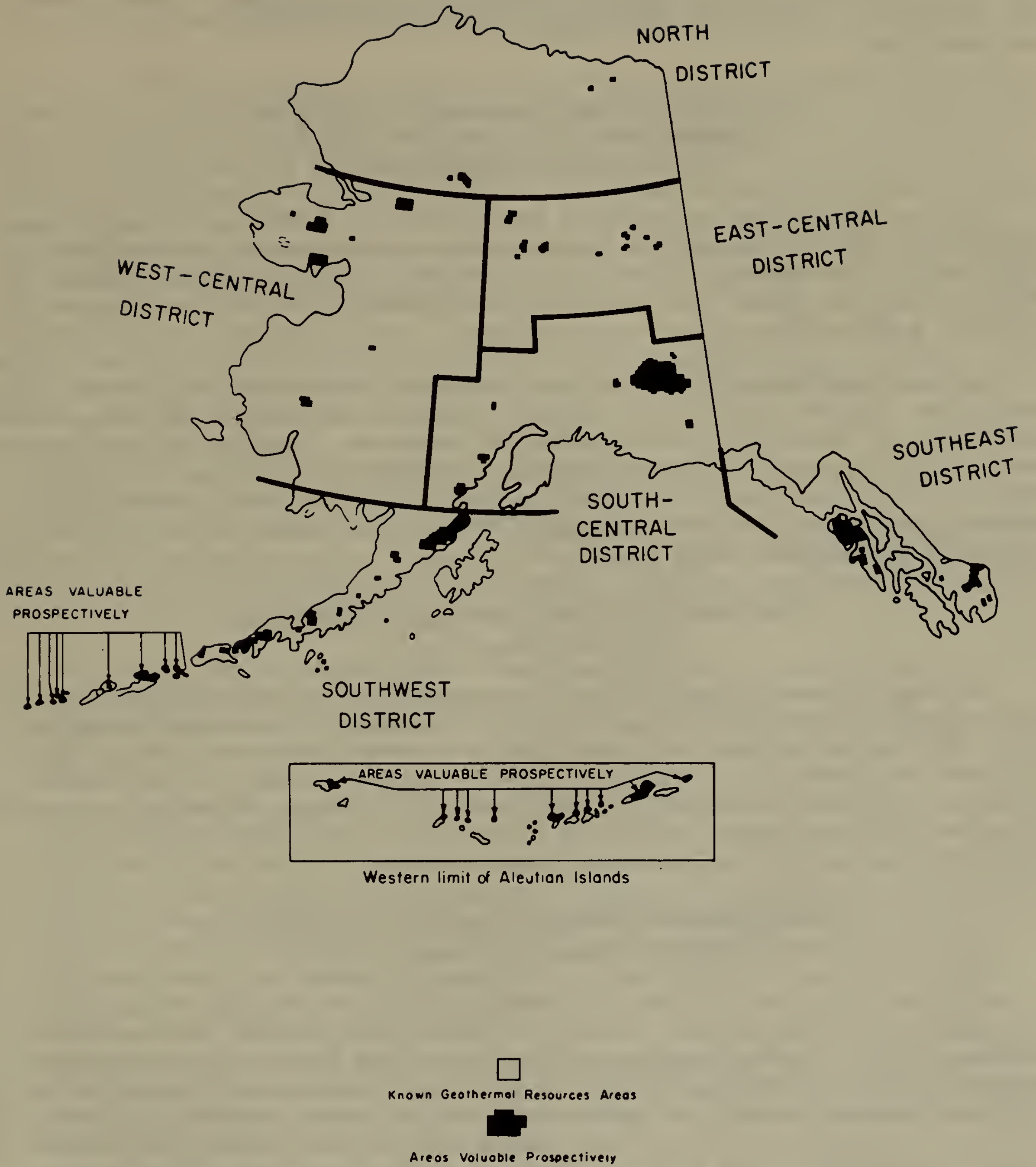

FIGURE 1. - Geothermal resources of Alaska by MINFILE district.

North District (North of Lat. 67°)

Relatively few hot springs have been found in northern Alaska, possibly because of the lack of favorable geologic conditions, such as the occurrence of granitic plutons (28). Calculated heat-flow values from drill hole data near Cape Thompson, Barrow, and Umiat are close to the normal world average

(5). Only two areas in the north district, both in the Brooks Range, have been identified by the U.S. Geological Survey as Geothermal Resource Provinces (GRP).

East-Central and West-Central Districts (Between Lat. 59° N and Lat. 67° N, Except South-Central District)

At least 39 hot springs are now known in these districts. Chemical geothermometers suggest subsurface temperatures in the general range of 100° to 160° C within the depths of 9,000 to 15,000 feet. If hot magmatic water or other dilution or mixing has occurred, these temperatures may be reached at shallower depths (18).

Current and historical use of hot springs in this district has been for bathing and limited agricultural purposes (18). Although currently used for recreation, no large-scale development has occurred. Pilgrim Springs, approximately 50 miles north of Nome, is currently being investigated by private interests for production of electricity for the city of Nome, nearby gold-dredging operations, and the proposed fluorite development at Lost River 100 miles northwest of Nome (12, 22).

Southwest District (South of Lat. 59° N, West of Long. 151° W)

In terms of area, this district represents only a small fraction of any other district except the southeast; yet it contains 34 of Alaska's approximately 100 thermal springs and more than 40 recently active volcanoes (17). It is not surprising that there are so many thermal springs in the Alaskan Peninsula and Aleutian Island volcanic belt (5). Except for Kodiak Island and the Bristol Bay drainages, more than 50 percent of this district has been classified by the U.S. Geological Survey as GRP's.

South-Central District (South of Lat. 64° N, Between Long. 141° W and 156° W)

Although only two of Alaska's thermal springs as reported by the U.S. Geological Survey lie in this region, it holds great promise for geothermal development (5). An exploratory well being drilled for oil on the Iniskin Peninsula about 160 miles southwest of Anchorage encountered flowing hot salt water and steam at a depth of approximately 8,500 feet. According to the driller's log, the well flowed for 2 hours at a pressure of 375 psi without signs of letup (26). The Wrangell Mountain GRP is the largest contiguous classification made in Alaska by the U.S. Geological Survey.

Energy needs of this district, containing approximately 80% of the State's population, are currently being provided by hydropower, coal, oil, and natural gas. However, international energy demands with the resulting escalated costs for these forms of energy may give rise in the future to serious consideration of the development of geothermal energy.

Southeast District (South of Lat. 60°30' N, East of Long. 141° W)

The southeast district contains 20 of Alaska's approximately 100 thermal springs as reported by the U.S. Geological Survey (15). This represents the second greatest ratio of regional area to thermal springs, exceeded only by the Aleutian Island and Alaska Peninsula (southwest) district. The most significant concentrations of springs with the highest temperatures are located in the Aleutian (southwest) and Alexander Archipelago (southeast) districts (15). According to the sodium-potassium-calcium temperature curves derived by T. P. Miller, reservoir temperatures of some of the southeastern Alaska thermal springs could be 170° C, which suggests that this province deserves further exploratory attention (16). Another favorable factor regarding this region lies in the fact that nearly all of the thermal springs are near the ocean. Thus, transportation costs for ultimate energy utilization for commodity import or export are enhanced.

GEOTHERMAL STEAM ACT OF 1970

The Geothermal Steam Act of 1970 extended the U.S. Geological Survey's authority and responsibility of classifying lands under the mineral leasing laws to include lands valuable for geothermal steam and associated geothermal resources. The act defines a GRP as follows (24):

> "an area in which higher than normal temperatures are likely to occur with depth and in which there is a reasonable possibility of finding reservoir rocks that will yield steam or heated fluids to wells."

A Known Geothermal Resources Area (KGRA) is defined as follows (24):

> "an area in which the geology, nearby discoveries, competitive interests, or other indicia would, in the opinion of the Secretary [of the Interior], engender a belief in men who are experienced in the subject matter that the prospects for extraction of geothermal steam or associated geothermal resources are good enough to warrant expenditures of money for that purpose."

If lands to be leased under this act are within any KGRA, they are to be leased by competitive bidding under regulations formulated by the Secretary of the Interior. If the land is not within a KGRA, the lease is to be awarded to the first qualified person who applies for it.

Although the disposal of lands containing geothermal resources is subject to the same restrictions as land containing other minerals, the law does not pertain to patents, grants, etc., that were made before the act was passed. This then poses the question: Do mineral reservations by the Federal or State Government contained in any grant or sale prior to the Geothermal Steam Act reserve to the Government all minerals including geothermal resources? (1). About 7 million acres in Alaska (approximately 2%) had been patented prior to the enactment of the Geothermal Steam Act of 1970. Thus, a conflict between

landowner and geothermal exploitation could arise if geothermal resources are found on or under private landholdings.

The U.S. Code of Federal Regulations (23) defines minerals as follows:

> "Whatever is recognized as a mineral by the standard authority, whether metallic or other substance, when found in public lands in quantity and quality sufficient to render the lands valuable on account thereof, is treated as coming within the purview of the mining laws."

The Department of the Interior (8) has also defined a mineral as

> "...every inorganic substance that can be extracted from the earth for profit, whether it be solid... or fluid, as mineral waters, petroleum, and gas."

Two areas are classified as KGRA's in Alaska: (1) Pilgrim Springs on the Seward Peninsula in northeast Alaska, and (2) Geyser Spring Basin and Okmok Caldera on Umnak Island in the Aleutian Island chain (7). The combined KGRA area is 492,572 acres. The U.S. Geological Survey has also classified an additional 10,781,581 acres within Alaska as GRP's under the terms of the Geothermal Steam Act of 1970 (27). Figure 1 shows these lands classified as geothermal resources.

POTENTIAL FOR DEVELOPMENT

The potential for developing a geothermal resource hinges upon the actual existence of a geothermal reservoir and its characteristics. Finding a geothermal reservoir entails an extensive exploration program utilizing geologic mapping, geochemical investigations, geophysical work, resistivity surveys, magnetic measurements, and microseismic surveys. Once the existence of a reservoir is indicated, a well must be drilled and the reservoir tested to assess its commercial potential.

Potential uses of geothermal resources include power generation, space heating, agriculture, refrigeration, industrial processing, production of fresh water by desalination, and byproduct chemical, mineral, and gas resources. Manufacturing and processing using geothermal energy is being done commercially in Iceland, New Zealand, and the U.S.S.R. The U.S.S.R. also uses geothermal resources for refrigeration and byproduct chemical applications.

In this report, the potential for power generation, space heating, and agriculture were examined for three sites: Kobuk, Unalaska, and Stikine River (fig. 2). In all cases, the geothermal sites were assumed to be developed to generate electrical power for mining ventures and nearby towns. Space heating and agricultural uses were assumed to be possible subsidiary uses of the geothermal resources after the water is used to generate power but before it is reinjected into the geothermal reservoir. In agricultural use, the cost of all facilities such as roads was borne by the powerplant. Thus, in effect,

FIGURE 2. - Index map of Alaska.

giving a minimum figure for the produce grown. The charge for water covered the cost of bringing it to the greenhouses.

Power Applications

The generation of electrical power from geothermal steam is currently being done commercially in a number of countries. The following tabulation shows 1972 production, in megawatts:

Iceland: Namafjall	3
Italy:	
Larderello	365
Monte Amiata	26
Japan:	
Matsukawa	20
Otake	12
Mexico:	
Cerro Prieto	[1]75
Pathe	1/2
New Zealand: Wairakei	192
U.S.S.R.: Pauzhetsk	5
United States: The Geysers, Calif.	[1]412

[1]1973 production.

At The Geysers, Calif., and in Larderello, Italy, steam comes directly to the surface as a vapor. At Wairakei, New Zealand, and Cerro Prieto, Mexico, steam comes to the surface in hot brines, and the vapor is recovered when the pressure is reduced. In either case, the steam vapor drives a turbine that generates electricity.

When reservoirs are predominantly hot water, electricity can be generated using heat exchangers, in a binary-cycle plant. Hot water, or a water and steam mixture, is used to heat a second fluid that has a low vaporization temperature, such as isobutane, pentane, or Freon.[5] When vaporized, the second fluid drives a turbine, is cooled, and is reused in a closed cycle.

Figure 3 shows a typical binary-cycle electrical generating plant. Incoming steam is separated from the hot brine, and both mediums are routed to heat exchangers, which heat the low-vaporization-temperature fluid to a vapor used to drive the generators. After passing through the heat exchangers, the brine and steam are reinjected into the geothermal reservoirs (11).

One problem with the binary-cycle plant is the lack of operating data. This system is in the design or pilot-plant stage of development and, although contracts have been let to construct several plants, no commercial binary-cycle plant was operating full time as of May 1974. Therefore, determining the economics of constructing and operating this type of plant at remote sites

[5]Reference to specific trade names or companies is made for information only and does not imply endorsement by the Bureau of Mines.

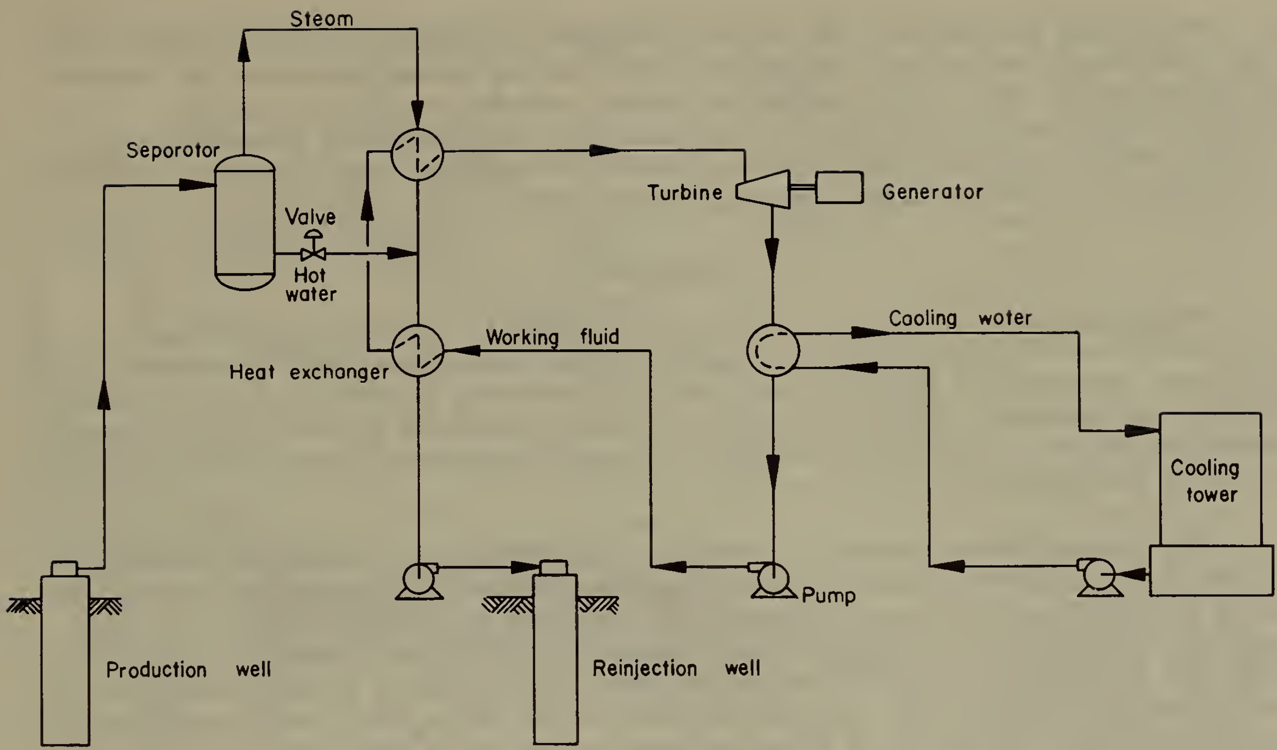

FIGURE 3. - Geothermal power-generating system.

in Alaska (where reservoir characteristics are also unknown) results in highly speculative estimates.

Power Applications in Alaska

To derive the capital and operating costs for generating electricity from geothermal sources at three remote sites in Alaska required several assumptions. The first one was the existence of a viable mineral deposit located near a geothermal source. Although minerals did occur in close proximity to hot springs, their reserves had to be assumed sufficient to last 20 years. All reservoirs were assumed to exist at a depth of 8,000 feet and to be sufficiently permeable to allow the withdrawal and reinjection of large quantities of water. No reinjection pumps were assumed necessary because the 8,000-foot head and pressure of the brine coming from the generators was expected to be adequate to return the brine to the reservoir. Cooling towers were considered unnecessary in Alaska; the low air temperatures and the existence of large quantities of surface cold water nearby should provide ample cooling mediums, particularly during the nonsummer months. All reservoirs were assumed to provide 177° C brine to the plants. Binary-cycle plants were assumed to produce 6,550 net kW at 2,000 gpm (11). Basic cost data for various sizes of binary-cycle plants located in southern California were supplied by the Ben Holt Co. All cost data were then modified by the authors to fit the various locations chosen for this study.

The price derived for the power generated included a 12% discounted cash flow (DCF) rate of return. Power derived from geothermal sources was assumed to be generated by a profit-oriented mining company or its subsidiary. Should a municipality, electrical association, or electrical cooperative attempt to develop the same sources, the price required would exclude profits and hence be closer to the operating costs given.

Kobuk Site

The Kennecott Copper Corp. has done exploration work north of Kobuk (fig. 2). At least two massive copper sulfide zones have been discovered that show the existence of pyrite, chalcopyrite, bornite, chalcocite, sphalerite, galena, and silver. The ore reserves for the Kennecott properties have never been published, but they are thought to be approximately 20 to 35 million tons of 4% to 6% copper (2).

The assumed development of geothermal power for the Kennecott properties is shown in figure 4; however, the company has never indicated what properties would be developed or where the mill and townsite would be located. To utilize the geothermal potential of the area may require an investigation of the four hot springs 50 to 70 air miles south of the proposed townsite, although an intensive study of the area may result in hot water being discovered closer to the proposed townsite. A drilling program would be necessary to determine which site might be suitable for geothermal power.

For the purpose of presenting possible costs of developing geothermal power, the site at Division was assumed to have suitable reservoir characteristics. The Division site would be 56 miles via the transmission lines from the townsite. The geothermal site would be serviced by aircraft, thus eliminating the expense of a road.

Electricity requirements for a 6,000-ton-per-day open stope underground mine and concentrator would be approximately 30 MW. The requirements for the townsite would be about 4 MW, based upon a work force of 720 employees, and 140 auxiliary townsite jobs. A total of 2,600 people was estimated for the town (2). Assuming each person requires 1.5 kW of generator capacity, 3 MW of generator capacity would be required for the townsite (3). An additional 3 MW of generator capacity would be required for geothermal pumps. An electrical generating plant consisting of three 20-MW binary-cycle generators was assumed adequate for the mine, concentrator, and townsite. One generator would be held for standby use.

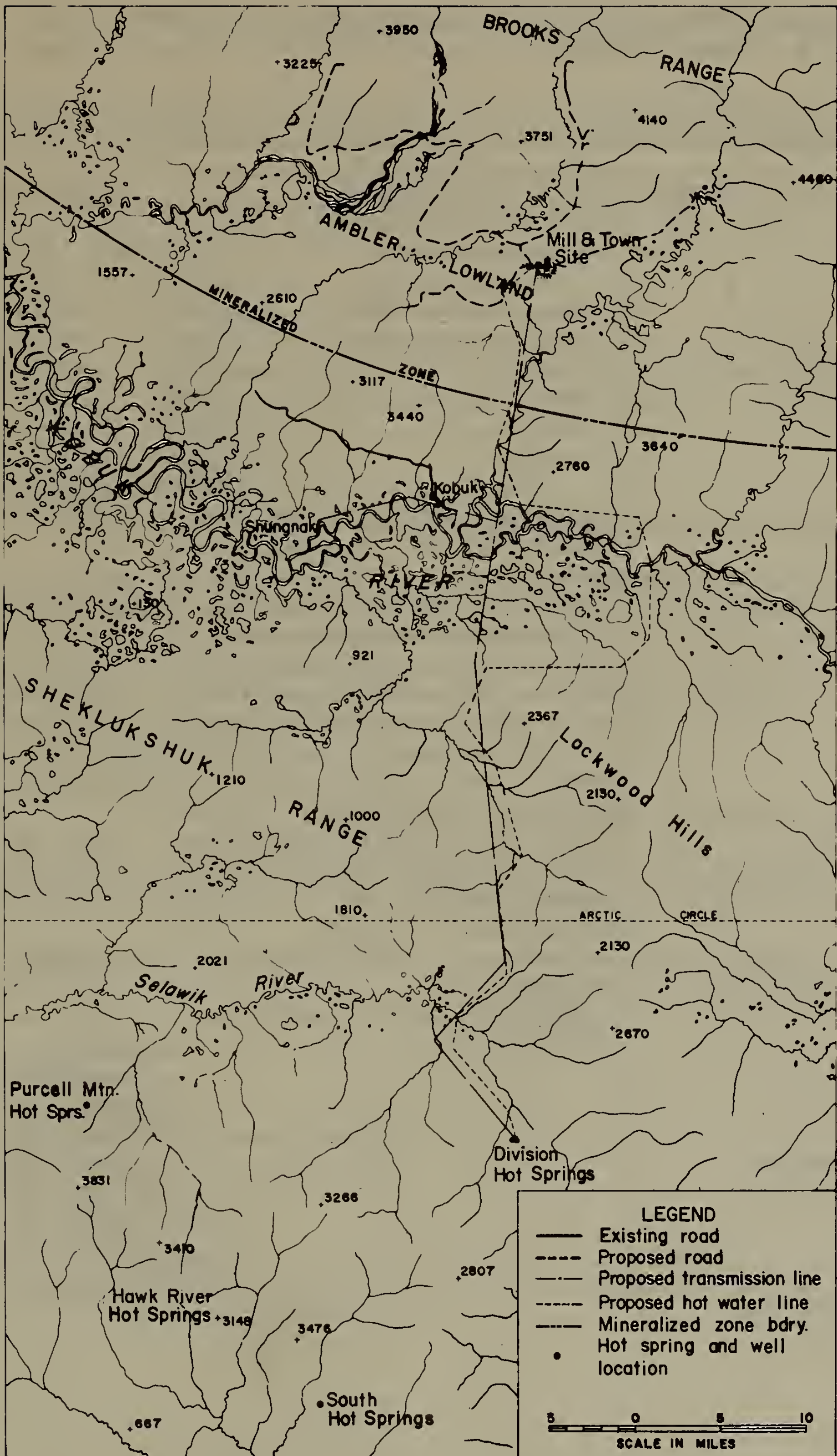

FIGURE 4. - Vicinity map of Kobuk, Alaska.

The total cost for the generating facility, including wells, pumps, piping, transmission lines, and roads, was $74.7 million (table 1). Twelve wells drilled on a four-by-three grid pattern 660 feet apart were assumed adequate to provide hot brine to the generators located at the center of the grid. Even if ideal conditions do not prevail, 8 of the 12 wells were assumed to provide sufficient quantities of hot water. Hot brine would be drawn from each of the outer eight wells at a rate of 1,500 gpm and reinjected after use in the four inner wells at a rate of 3,000 gpm. It was assumed that 500-hp pumps would be adequate to pump the water against a 1,000-foot head to the surface and into the plant.

Operating costs for the binary-cycle plant were $10.1 million to produce 350.4 million Kw-hr per year of electricity, or 2.87 cents per kW-hr (table 2). Operating costs included wages;

fringes; operating supplies and parts for the generators; replacement of 20% of the production string, pumps, and surface pipes each year; and maintenance of transmission lines.

TABLE 1. - Capital cost for geothermal powerplant, Kobuk site

Item	Number	Description	Cost
Well	12	8,000 ft, 9-5/8-in-diam production casing: Exploration .... $200,000 Site construction ... 18,600 Drilling rig rental. 272,700 Cement .... 184,700 Bits .... 28,000 Mud .... 31,600 Casing .... 115,300 Total 850,900	$10,210,800
Pump	9	1,500 gpm, 500 hp, stainless steel fittings, 1 spare, installed.	775,800
Piping	-	7,572 ft of 10-in, 12-in, and 20-in diam, stainless steel, with fittings, installed.	1,042,700
Road	-	7,260 ft of service road for wells, 18-ft-wide gravel road at $200,000/mi.	275,000
Generator	3	20-MW binary-cycle type at $710/kW, installed.	42,600,000
Transformer substation	1	40,000 kW at $30/kW, installed	1,200,000
Transmission line	-	56 mi of 138-kV line, helicopter erection at $95,000/mi, erected.	5,320,000
Airplane	1	4-passenger, 1,000-lb load capacity.	30,000
Runway	1	5,000-ft by 200-ft runway at $200/lin ft.	1,000,000
Subtotal	-	-	62,454,300
Contingency	-	-	6,245,400
Subtotal	-	-	68,699,700
Interest during construction	-	-	3,435,000
Total for depreciation	-	-	72,134,700
Working capital[1]	-	-	2,518,000
Total capital requirements	-	-	74,652,700

[1] 25% of annual operating cost.

TABLE 2. - Estimated annual cost for geothermal powerplant, Kobuk site

Item	Description	Cost
Generator	Employee wages, fringes, operating supplies, parts.	$600,000
Wells	Casing replacement, 20% of casing materials.	276,700
Plant facilities	0.1% of generator cost	42,600
Pumps	20% of pumps	137,900
Piping	20% of pipe materials	208,500
Transmission line	Maintenance at 2% of investment	106,400
Airplane	1,100 hr/yr of operation at $40/hr	44,000
Fixed and indirect costs	7% of total investment	5,049,400
Depreciation	5% of total investment	3,606,700
Total	-	10,072,200

Power cost = $10,072,200 ÷ 350,400,000 kW-hr/yr = $0.0287/kW-hr.

By way of comparison, a diesel-powered generating plant of comparable size located at the mine-concentrator site was estimated to cost $41.6 million (table 3). This type of facility required 56% of the capital for a binary-cycle plant. Operating costs for this type of system were 5.07 cents per kW-hr with fuel costing 49.0 cents per gallon (table 4). Should fuel costs rise further, the differences in annual operating costs of the geothermal and diesel powerplants would widen.

TABLE 3. - Capital cost for diesel powerplant, Kobuk site

Item	Number	Description	Cost[1]
Diesel generators	6	10,000-kW generators at $500/kW.	$30,000,000
Transformer substation	1	40,000 kW at $30/kW	1,200,000
Fuel tank	1	100,000-bbl aboveground steel tank.	943,800
Subtotal	-	-	32,143,800
Contingency	-	-	3,214,400
Subtotal	-	-	35,358,200
Interest during construction	-	-	1,767,900
Total for depreciation.	-	-	37,126,100
Working capital[2]	-	-	4,444,400
Total capital requirement.	-	-	41,570,500

[1]Cost installed.

[2]25% of annual operating cost.

TABLE 4. - Estimated annual cost for diesel powerplant, Kobuk site

Item	Description	Cost
Generator	Employee wages, fringes, operating supplies, parts.	$1,876,000
Fixed and indirect costs	7% of investment	2,598,800
Depreciation	5% of investment	1,856,300
Fuel	23,360,000 gal at $0.49/gal	11,446,400
Total	-	17,777,500

Power cost = $17,777,500 ÷ 350,400,000 kW-hr/yr = $0.0507/kW-hr.

To properly assess the merits of the various alternatives for a profit-oriented company, the time value of money was considered. Assuming a 12% DCF rate of return over a 20-year life, electricity was produced for 6.52 cents per kW-hr by the binary-cycle plant, and 7.19 cents for the diesel generating plant (table 5).

TABLE 5. - Comparative financial analyses, Kobuk site (12% DCF, 20-yr life)

	Geothermal powerplant	Diesel powerplant
Positive cash flow[1]	$9,995,000	$5,565,700
Less depreciation	3,606,700	1,856,300
Net profit	6,388,300	3,709,400
Revenues	22,848,800	25,196,300
Less operating costs	10,072,200	17,777,500
Taxable income	12,776,600	7,418,800
Less State and Federal taxes	6,388,300	3,709,400
Net profit	6,388,300	3,709,400

Price per kilowatt-hour for geothermal generation = $22,848,800 ÷ 350,400,000 kW-hr = $0.0652.
Price per kilowatt-hour for diesel generation = $25,196,300 ÷ 350,400,000 kW-hr = $0.0719.

[1] Derived by dividing total capital investment from tables 1 and 3 by present-worth factor of 7.469.

Unalaska Site

The Biorka zinc deposit is located on Sedanka Island about 15 miles southeast of Unalaska (fig. 2). The fault zone across Sedanka Island is approximately 3 miles long. About 240 feet of the fault zone was sampled in 1945 by Bureau of Mines engineers and showed an average of 6.8% zinc, 0.19% lead, and 0.33% copper. The mineralized areas in the fault zone ranged up to 60 feet in width and averaged about 45 feet (29). The average ore grade and the ore tonnage in the entire fault zone is unknown. For the purpose of this report, 2,260,000 tons of zinc ore was assumed to exist, enough to support a

500-ton-per-day shrinkage stope mine and adjacent concentrator for 20 years. Power requirements for the 500-ton-per-day mine and concentrator would be approximately 1 MW, with an additional 0.75 MW required for the use of the miners and their families.

One method of developing the deposit would be to place all facilities on Sedanka Island and provide the necessary power with a 2-MW diesel generator (plus one unit on standby). The capital cost for the installation was estimated to cost $2.0 million (table 6). The cost to generate electricity with diesel fuel costing 42 cents per gallon was 5.40 cents per kW-hr (table 7).

TABLE 6. - Capital cost for diesel powerplant, Unalaska site

Item	Number	Description	Cost[1]
Diesel generators...........	2	2,000-kW generators at $325/kW	$1,300,000
Transformer station.........	1	2,000-kW at $25/kW............	50,000
Fuel tank...................	1	200,000-gal aboveground steel tank.	264,200
Subtotal..............	-	-	1,614,200
Contingency.................	-	-	161,400
Subtotal..............	-	-	1,775,600
Interest during construction	-	-	88,800
Total for depreciation.	-	-	1,864,400
Working capital[2]...........	-	-	147,200
Total capital requirement.	-	-	2,011,600

[1]Cost installed.
[2]25% of annual operating cost.

TABLE 7. - Estimated annual cost for diesel powerplant, Unalaska site

Item	Description	Cost
Generator.................	Employee wages, fringes, operating parts at $30/kW.	$60,000
Fixed and indirect costs..	7% of investment.........................	130,500
Depreciation..............	5% of investment.........................	93,200
Fuel......................	726,000 gal at $0.42/gal.................	304,900
Total...............	-	588,600

Power cost = $588,600/yr ÷ 10,890,000 kW-hr = $0.0540/kW-hr.

A second method of supplying electrical power for the development of the zinc deposit would be through the utilization of the potential geothermal resources near Unalaska (fig. 5). Power could then be provided to Unalaska as well as the mine. One 2-MW binary-cycle generator and one 2-MW standby diesel generator would be installed and connected to the mine and concentrator via a 5-mile marine cable and a 6-mile overhead transmission line. An 8-mile overhead line would connect the geothermal site to Unalaska. A 16-mile gravel road would connect the geothermal site to Unalaska. Finally, a ferry system with terminals on Beaver Inlet would be necessary to connect the geothermal site with the mine and concentrator.

FIGURE 5. - Vicinity map of Unalaska, Alaska.

The total cost of the installation, including roads and transmission lines, wells, pumps, and piping, was $10.7 million for a system with a binary-cycle plant (table 8). The cost of the electricity generated was 11.04 cents per kW-hr (table 9). Two wells with a 6-inch production casing were assumed necessary, one for bringing brine to the plant and one for reinjection of fluids back into the reservoir. A 150-hp pump was needed to bring 600 gpm of brine to the generator against a 1,000-foot head.

TABLE 8. - Capital cost for geothermal powerplant, Unalaska site

Item	Number	Description	Cost
Well	2	8,000 ft, 6-in-diam production casing: Exploration..........$100,000 Site construction.... 7,500 Drilling rig rental.. 204,900 Cement............... 32,800 Bits................. 14,900 Mud.................. 19,900 Casing............... 61,900 Total............. 441,900	$883,800
Pump	2	600 gpm, 150 hp, stainless steel fittings, 1 spare, installed.	86,200
Piping	-	660 ft of 6-in diam, stainless steel, with fittings, installed	26,200
Road	-	660 ft of service road for the wells, 18-ft-wide gravel road at $150,000/mi.	18,800
Generator	1	2-MW binary-cycle type at $1,630/kW, installed.	3,260,000
Generator	1	2-MW diesel electric generator at $325/kW, installed, standby service.	650,000
Fuel tank	1	50,000-gal aboveground steel tank.	83,100
Transformer substation	1	2,000 kW at $25/kW, installed..	50,000
Transmission line	-	11 mi of 33-kV line, 14-mi overland helicopter erection, 5 mi underwater, $75,000/mi average.	1,425,000
Road	-	16 mi of 18-ft gravel road to ferry terminal and townsite at $150,000/mi.	2,400,000
Subtotal	-	-	8,883,100
Contingency	-	-	888,300
Subtotal	-	-	9,771,400
Interest during construction	-	-	488,600
Total for depreciation.	-	-	10,260,000
Working capital[1]	-	-	409,400
Total capital requirements.	-	-	10,669,400

[1] 25% of annual operating cost.

TABLE 9. - Estimated annual cost for geothermal powerplant, Unalaska site

Item	Description	Cost
Generator	Employee wages, fringes, operating supplies, parts.	$225,000
Wells	Casing replacement, 20% of casing materials.	24,800
Plant facilities	0.1% of generator cost	3,900
Pumps	20% of pumps	8,600
Piping	20% of pipe materials	5,200
Transmission lines	2% of investment for maintenance	28,500
Road	2% of investment for maintenance	48,000
Fuel	148,000 gal at $0.42/gal	62,200
Fixed and indirect costs	7% of total investment	718,200
Depreciation	5% of total investment	513,000
Total	-	1,637,400

Power cost = $1,637,400 ÷ 14,832,000 kW-hr = $0.1104/kW-hr.

Table 10 shows the cost of producing electrical power including a 12% DCF rate of return. Diesel power then costs 8.64 cents per kW-hr; power generated via the binary-cycle plant costs 23.38 cents per kW-hr.

TABLE 10. - Comparative financial analyses, Unalaska site (12% DCF, 20-yr life)

	Geothermal powerplant	Diesel powerplant
Positive cash flow[1]	$1,428,500	$269,300
Less depreciation	513,000	93,200
Net profit	915,500	176,100
Revenues	3,468,400	940,800
Less operating costs	1,637,400	588,600
Taxable income	1,831,000	352,200
Less State and Federal taxes	915,500	176,100
Net profit	915,500	176,100

Price per kilowatt-hour for geothermal generation = $3,468,400 ÷ 14,832,000 kW-hr = $0.2338.

Price per kilowatt-hour for diesel generation = $940,800 ÷ 10,890,000 kW-hr = $0.0864.

[1] Derived by dividing total capital costs from tables 6 and 8 by the present-worth factor of 7.469.

In this situation, the mining company could produce its required electricity with diesel generators cheaper than it could by geothermal methods. The factors working against geothermal power were the road and transmission system, coupled with the relatively small amount of power required. The cost

to drill two deep holes and the cost of the geothermal generator added significantly to the cost of electricity.

Stikine River Site

The lead-zinc deposits of Groundhog and Glacier Basins are located about 13 air miles east of Wrangell (fig. 2). An estimated 5 million tons of massive and disseminated sulfides and sulfide-bearing minerals occur as tabular replacement veins in fine-grained gneisses and schists that trend N 30° W and dip 50° to 80° east. The veins range from a few inches to 30 feet in thickness, but most are on the order of 1.5 to 10 feet (2, 6).

Since the surface mineral deposits occur in an area mostly covered with snow and prone to avalanches, mining could commence by driving an adit at a lower elevation parallel to the strike of the beds. Crosscuts to the ore bodies could be made and the ore mined by shrinkage stoping methods. If 1,000 tons of ore were mined each day, 235 days per year, reserves would last 20 years. Power requirements for the mine and concentrator would be approximately 2 MW. The 270 employees would bring about 1,000 people to the area, presumably to live in Wrangell (2). The power requirements for the additional residents would be about 1.5 MW based on electrical requirements of 1.5 kW per person (3).

Electrical power for the mining venture could be provided by a number of methods. The cheapest alternative from the point of initial cost would be the purchase of two 2-MW diesel generators for installation near the mine and concentrator site. The capital cost would be about $1.5 million for the generators, facilities, and fuel tanks (table 11). Operating costs, including fuel at 35 cents per gallon, would be 4.35 cents per kW-hr (table 12).

TABLE 11. - Capital cost for diesel powerplant, Stikine River site

Item	Number	Description	Cost[1]
Diesel generators	2	2,000-kW generators at $260/kW	$1,040,000
Transformer station	1	2,000 kW at $20/kW	40,000
Fuel tank	1	120,000-gal aboveground steel tank.	105,400
Subtotal	-	-	1,185,400
Contingency	-	-	118,500
Subtotal	-	-	1,303,900
Interest during construction	-	-	65,200
Total for depreciation.	-	-	1,369,100
Working capital[2]	-	-	115,000
Total capital requirement.	-	-	1,484,100

[1]Cost installed.
[2]25% of annual operating cost.

TABLE 12. - Estimated annual cost for diesel powerplant, Stikine River site

Item	Description	Cost
Generator................	Employee wages, fringes, operating supplies, parts.	$48,800
Fixed and indirect costs..	7% of investment..........................	95,800
Depreciation..............	5% of investment..........................	68,500
Fuel......................	705,395 gal at $0.35/gal..................	246,900
Total...............	-	460,000

Power cost = $460,000/yr ÷ 10,580,900 kW-hr = $0.0435/kW-hr.

A second alternative might be the formation of a subsidiary utility to use the potential geothermal resources at Chief Shake's hot springs adjacent to the Stikine River and approximately 14 air miles north of the mine site (fig. 6). The installation of a 20-MW geothermal plant at this site would allow the tie-in of electrical generating plants at Petersburg and Wrangell, the replacement of diesel generators now providing power to the two communities, the generation of electricity at cheaper rates, and the possible expansion of the local economy through the sale of hot water for agriculture and perhaps recreational purposes. The credit from the sale of hot water would lower the cost of the electricity generated.

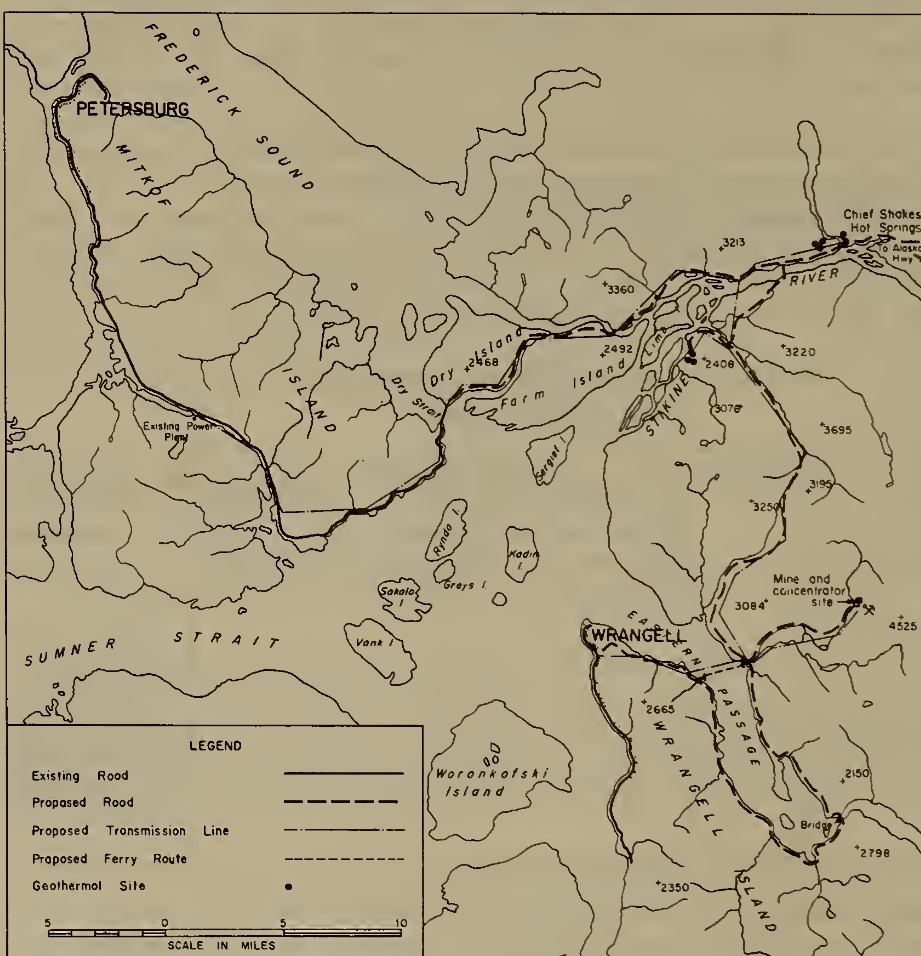

FIGURE 6. - Vicinity map of Stikine River, Alaska.

The utilization of the geothermal resources could be accomplished by drilling six wells with a production casing diameter of 8-5/8 inches--four for pumping 1,500 gpm of water out

of the geothermal reservoir and two for putting water back into the formation. Presumably four of the six wells would be able to supply the needed water. The two poorest producing wells would be used for reinjection. The cost of a two-generator system was estimated to be $27.7 million (table 13). The utility would construct the transmission line intertie between the geothermal site, Wrangell, the powerplant south of Petersburg, and the mine site. The road was assumed to be constructed by the State of Alaska along a route already proposed. The company would construct the road to the mine and concentrator site.

TABLE 13. - Capital cost for geothermal powerplant, Stikine River site

Item	Number	Description	Cost
Well	6	8,000 ft, 8-5/8-in-diam production casing: Exploration $150,000; Site construction 12,500; Drilling rig rental 272,700; Cement 56,500; Bits 22,400; Mud 22,800; Casing 76,900; Total 613,800	$3,682,800
Pump	5	1,500 gpm, 500-hp stainless steel fittings, 1 spare, installed.	431,000
Piping	-	3,300 ft of 10-in and 14-in diam, stainless steel, with fittings, installed.	420,700
Road	-	3,300 ft of service road for wells, 18-ft wide, gravel, at $140,000/mi.	87,500
Generator	2	10-MW binary-cycle type at $740/kW.	14,800,000
Transformer station	1	20,000 kW at $20/kW	400,000
Transmission line	-	60 mi of 60-kV line, helicopter erection at $55,000/mi	3,300,000
Subtotal	-	-	23,122,000
Contingency	-	-	2,312,200
Subtotal	-	-	25,434,200
Interest during construction	-	-	1,271,700
Total for depreciation	-	-	26,705,900
Working capital[1]	-	-	995,200
Total capital requirements	-	-	27,701,100

[1] 25% of annual operating costs.

The cost to generate electricity using geothermal water, assuming no credit for water sold for other purposes, was 2.84 cents per kW-hr with the binary-cycle plant (table 14). These costs include wages, fringes, operating supplies, parts, replacement of all pipes and fittings exposed to geothermal

water every 5 years, and maintenance of transmission lines. The cost of electricity to Petersburg in 1974 using diesel generators was 5.5 cents per kW-hr (20).

TABLE 14. - Estimated annual cost for geothermal powerplant, Stikine River site

Item	Description	Cost
Generator..............	Employee wages, fringes, operating supplies, parts.	$450,000
Wells..................	Casing replacement, 20% of casing materials.	92,300
Plant facilities........	0.1% of generator cost....................	14,800
Pumps..................	20% of pumps..............................	69,000
Piping.................	20% of pipe materials.....................	84,100
Transmission line.......	Maintenance at 2% of investment...........	66,000
Fixed and indirect costs	7% of total investment....................	1,869,400
Depreciation............	5% of total investment....................	1,335,300
Total..............	-	3,980,900

Power cost = $3,980,900 ÷ 140,160,000 kW-hr/yr = $0.0284/kW-hr.

The cost to generate electricity, including a 12% DCF rate of return, was 6.23 cents per kW-hr for the binary-cycle plant and 6.81 cents for the diesel generator (table 15). A municipal or cooperative electrical generating utility could sell power at rates much closer to its operating costs. A utility could also lower its operating costs by adopting a longer depreciation period.

TABLE 15. - Comparative financial analyses, Stikine River site (12% DCF, 20-yr life)

	Geothermal powerplant	Diesel powerplant
Positive cash flow[1]................................	3,708,800	198,700
Less depreciation...................................	1,335,300	68,500
Net profit.......................................	2,373,500	130,200
Revenues..	8,727,900	720,400
Less operating costs................................	3,980,900	460,000
Taxable income......................................	4,747,000	260,400
Less State and Federal taxes........................	2,373,500	130,200
Net profit.......................................	2,373,500	130,200

Price per kilowatt-hour for geothermal generation = $8,727,900 ÷ 140,160,000 kW-hr = $0.0623.
Price per kilowatt-hour for diesel generation = $720,400 ÷ 10,480,900 kW-hr = $0.0681.

[1]Derived by dividing total capital costs from tables 11 and 13 by the present-worth factor of 7.469.

Space Heating Applications

Geothermal hot water is currently employed for space heating in Hungary, Iceland, New Zealand, and the U.S.S.R. In the United States, Klamath Falls, Oreg. (over 400 buildings), and Boise, Idaho (over 200 homes), are the principal use locations.

In Klamath Falls, Oreg., over 300 homes, several public schools, a public hospital, and several light industrial plants use geothermal heat exchangers for space heating. In addition, the city of Klamath Falls employs geothermal waste water for under-pavement circulation to keep several intersections free of ice and snow during the winter.

Oregon Technical Institute at Klamath Falls has developed a very efficient system of geothermal space heating and domestic hot water heating, as illustrated in figures 7 through 12. At the school, over 440,000 square feet of building floor space is heated by heat exchangers utilizing hot geothermal water (21).

The Institute's three wells produce 191° F water, which is pumped into storage for gravity feed distribution to any building. Heat exchangers are employed for the forced-air space heating and the domestic hot water system. Geothermal water of 186° to 189° F is delivered to the various buildings at an annual cost of $12,000 to $14,000. Heating a smaller college complex with fuel oil cost $94,000 to $100,000 per year before fuel prices escalated (21). Water discharge is at 120° F; the water flows via the storm sewer system into Klamath Lake. Discharge into the lake is controlled by the city of Klamath Falls and is based on a ratio formula of cubic feet of waste geothermal water allowed versus square feet of floor space heated.

The Institute drilled six wells, three of which have water hot enough for their needs. Wells were drilled to depths of 1,300 to 1,800 feet and cost from $22,000 to $32,000 per well, including drilling, testing, and casing. An additional $10,000 per well provides plumbing, pumps, etc.

Most geothermal heating of homes is accomplished with a closed system, utilizing the natural hot water (fig. 13). A heat exchanger adequate for the area to be heated is set below the mean water level in the geothermal well. The heating medium, usually water, is then pumped through the exchanger and circulated in the building for heat withdrawal in a conventional baseboard system. This method does not consume any geothermal fluid.

Space heating utilizing geothermal hot water is a very efficient and economical method if the source can be developed within feasible distance of the consumer. If these general conditions can be developed in some of Alaska's remote locations, obvious benefits will accrue.

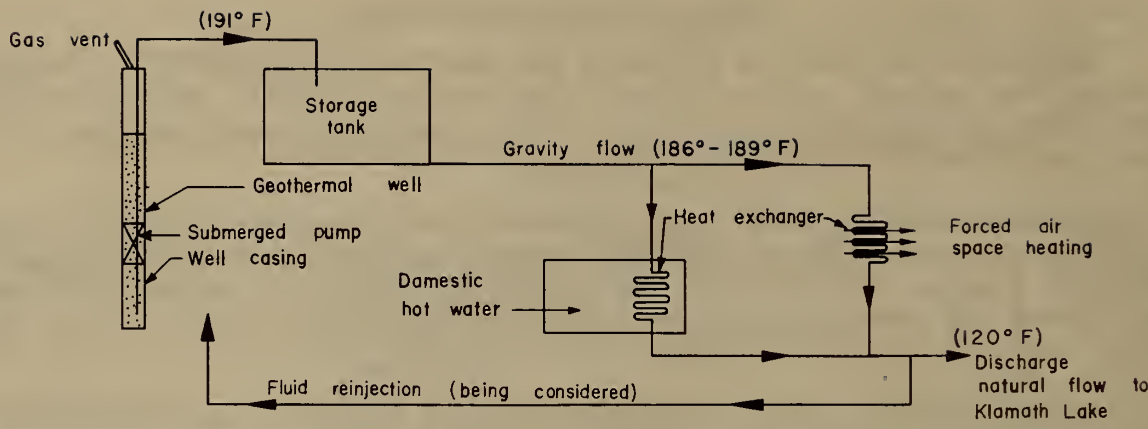

FIGURE 7. - Space heating system, Oregon Technical Institute, Klamath Falls, Oreg.

FIGURE 8. - One of three pump sites supplying geothermal heating water to Oregon Technical Institute (Klamath Falls, Oreg.).

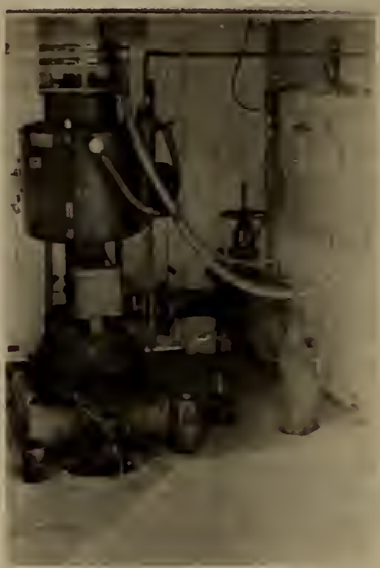

FIGURE 9. - Geothermal pump at Oregon Technical Institute (Klamath Falls, Oreg.).

FIGURE 10. - Water gage showing incoming geothermal water at Oregon Technical Institute (Klamath Falls, Oreg.).

FIGURE 11. - Holding tank for geothermal water at Oregon Technical Institute (Klamath Falls, Oreg.).

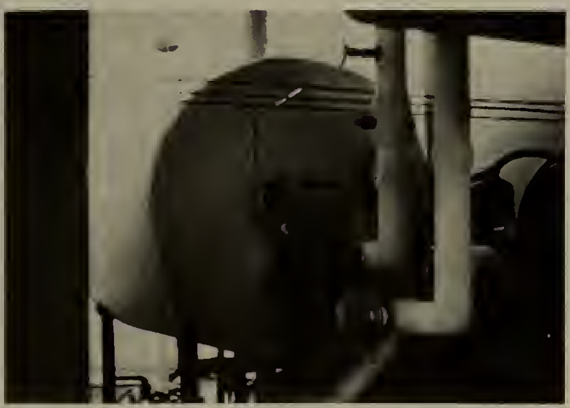

FIGURE 12. - Domestic hot water being heated by geothermal water at Oregon Technical Institute (Klamath Falls, Oreg.).

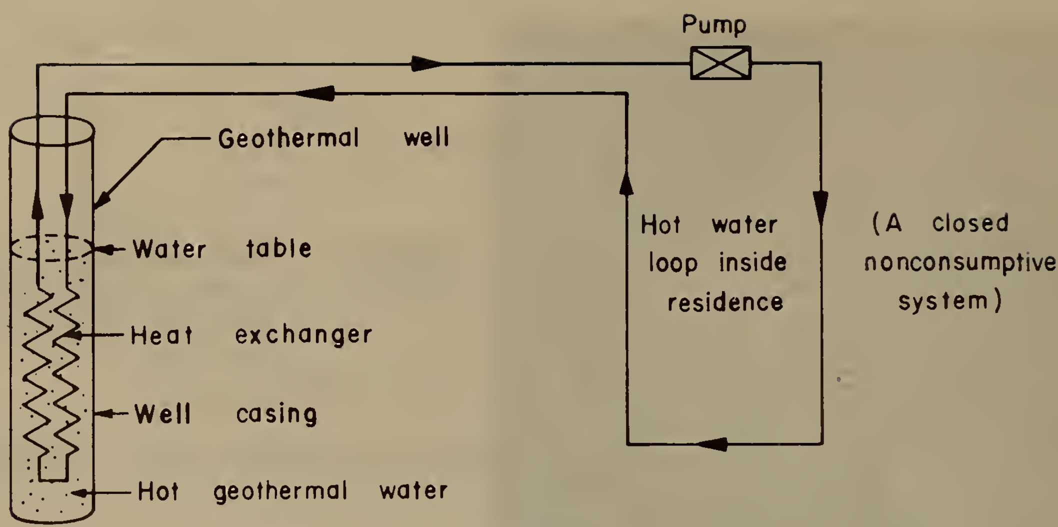

FIGURE 13. - Space heating system for residences, Klamath Falls, Oreg.

Space Heating Applications in Alaska

The economics of utilizing hot geothermal water as subsidiary uses to power generation was examined for the Kobuk, Stikine River, and Unalaska sites. In all cases, the cost to construct and operate a pipeline system from the point of geothermal production to the point of potential utilization was too great to compete with space heating costs using conventional hydrocarbon fuels. For example, the depreciation on the estimated cost of $88 million to build an insulated 16-inch pipeline 80 miles to the Kobuk mining area from the geothermal site would have been $4.4 million per year. Heating the townsite and company buildings by fuel oil would have cost an estimated $1.0 million. Hot water has been pipelined as far as 50 miles, but most systems are in the 10- to 30-mile range (19). In Alaska, several instances are known to the authors where people living adjacent to remote hot springs are utilizing water from hot springs to heat their homes.

Agriculture Applications

Geothermal water is currently being used for agricultural purposes in Iceland and the U.S.S.R. In the United States, a successful hydroponic (agricultural) operation is located at Wendell Hot Springs, 30 miles east of Susanville, Calif., and 80 miles north of Reno, Nev. Hobo Wells Hydroponics, Inc., of Jonesville, Calif., pumps water from the adjacent hot springs to their group of four greenhouses at an average rate of 23 gpm for each greenhouse. The 209° F water is routed to modified cooling towers in the summer or through a heat exchanger in the winter to obtain an ideal water temperature of 180° F (fig. 14). Fans draw off the warmed air from radiators located at each end of the building and blow it through a 20-inch-diameter plastic tube suspended from the ceiling running the full length of the greenhouse. Two-inch holes along the length of the tube provide even heating of the greenhouse (figs. 15-19).

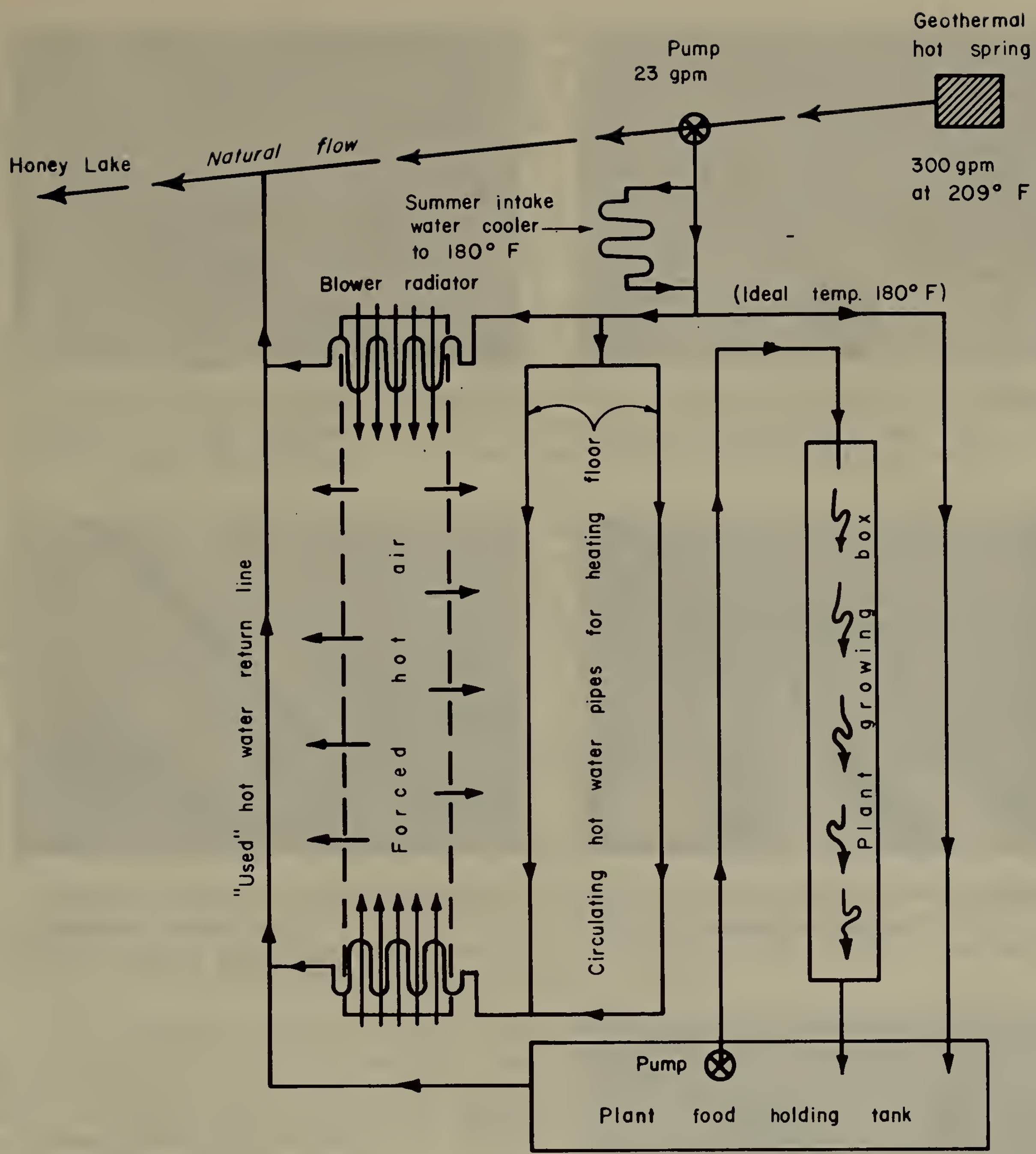

FIGURE 14. - Schematic diagram of a greenhouse heated by geothermal water, Hobo Hot Springs, Wendell, Calif.

Hot water is pumped through pipes embedded in six concrete walkways between the rows of plant trays, providing radiant heating as well. Warm water is also used in the nutrient tank where a mixture is prepared for plant feeding. Plants actually grow in 9-inch-thick beds of sterilized 1/4-inch to 3/8-inch pea gravel and are fed precise amounts of the nutrient mixture at regular intervals from a 5,000-gallon holding tank. Chemical plant nutrients

FIGURE 15. - Withdrawal of geothermal water from a natural hot spring at Wendell. Calif.

FIGURE 16. - Plant-food holding tanks and greenhouses under construction. Wendell. Calif.

FIGURE 17. - Completed greenhouse ready for planting, Wendell, Calif.

FIGURE 18. - Hot air from heat exchanger is forced through perforated plastic tube, Wendell, Calif.

FIGURE 19. - Interior of greenhouse at Wendell, Calif., showing heat-distribution system and finished product—vine-ripened tomatoes.

are mixed into the warm geothermal water and pumped from a holding tank to the plants four times daily. The plant food water enters at one end of the plant growing box and percolates to the opposite end, then flows by gravity back into the holding tank for later repeating of the cycle. Approximately 1,000 pounds of plant food at 40 cents per pound is required per house each year.

An average of 4 man-hours per day per house is required to prune, hand-pollinize, feed, and carry out general maintenance. Local labor averages $6 to $7 per hour, but ranges from $2 to $10 per hour.

Each of six 125-foot by 26-foot (3,250 sq ft) greenhouses is covered with 5,200 square feet of semitransparent fiberglass in the form of a quonset hut. Material costs for these buildings in May 1974, f.o.b. Wendell, were $16,000. Once constructed, maintenance costs are minimal. Approximately $50 per month is required for electricity for blowers, pumps, etc. The design is simple, but must be durable since 70- to 80-mile-per-hour winds and -25° F weather have occurred.

Tomatoes are the only crop produced but the company plans to expand into cucumber production also. Tomato plants are viable for 5 months, which allows for two growing seasons per year. Current tomato production is 35,000 to 38,000 pounds per house per year, including both crops. Tomatoes are sold for an average price of 50 cents per pound. The company's goal is to produce 40,000 pounds of vine-ripened tomatoes per house per year.

An operation of this type conducted in Alaska would have the advantage of summer's long daylight hours for increased plant production. Artificial lighting would probably be required during the winter months.

Agriculture Applications in Alaska

Several Alaskan hot springs may be suitable for agricultural development, particularly since some of these hot springs have developed transportation links and are reasonably close to markets. At least two hot springs are being utilized to heat greenhouses at remote sites in Alaska.

As geothermal energy sources are developed for electrical production, economics may be even more favorable for concurrent agricultural development. Owing to the relatively small water requirements, a shallow, small-diameter well could possibly be drilled to supply warm water for agricultural purposes only.

In this study, two types of operations are considered: (1) absentee ownership, where a company headquartered elsewhere in the State or Nation has the facility constructed on a turnkey basis and hires a resident to manage the facility; and (2) an owner-operator case, where individuals construct and operate the facility. Although the two facilities would be similar in construction and operation, the owner-operator facility would be cheaper to build and operate because the cost of labor would be less. For example, the owner-operators could use family members if additional help is required for a short time, whereas a company would have to hire the needed laborers. In this

study, the owner-operator was assumed to consist of two families who build and operate the greenhouses themselves. The total income to the owner-operators is arbitrarily set for each location. That income is then attained by adding the net profit to wages.

Kobuk Site

If a road were constructed from the townsite to the geothermal site, an agricultural business could be a possible consumer of waste hot water from the geothermal generators. In this section of the report, such a road is assumed to exist, thus allowing produce to be marketed at the townsite and nearby villages. Also, for the sake of simplicity, only one type of produce is grown, tomatoes.

Construction of the greenhouses was estimated to cost $472,500 if built by a contractor, or $141,300 if built by owner-operators (table 16). The basic costs before contingencies, interest during construction, vehicles, or working capital was $28 per square foot for the contracted units and $7 per square foot for those units constructed by the owner-operators.

TABLE 16. - Capital costs for greenhouses, Kobuk site

Item	Number	Description	Turnkey	Owner-constructed
Greenhouse	4	26-ft by 125-ft building, domed fiberglass roof, heating unit, at $28/sq ft, installed.	$364,000	-
Greenhouse	4	26-ft by 125-ft building, domed fiberglass roof, heating unit:		
		Materials, including transportation to the site.	-	$76,800
		Labor cost for 2 men to live for 6 months	-	15,000
Vehicles	2	3/4-ton pickups	10,000	10,000
Subtotal	-	-	374,000	101,800
Contingency	-	-	37,400	10,200
Subtotal	-	-	411,400	112,000
Interest during construction	-	-	20,600	5,600
Subtotal for depreciation.	-	-	432,000	117,600
Working capital[1]	-	-	40,500	23,700
Total investment	-	-	472,500	141,300

[1]25% of annual operating cost.

Operating costs for the contracted units were $161,900 per year versus $94,800 for the owner-operated greenhouses (table 17). The higher costs of the contracted units was due to the higher wages and fringe benefits paid, higher indirect costs necessitated by conferring with an absentee owner, and

higher depreciation costs due to the the greater investment. Labor was estimated to cost $7.50 per hour and supervision $24,000 per year. Wages plus taxable income for the owner-operated units totaled $53,000 annually. Water requirements were estimated to average 175 gpm for the four greenhouses combined. Electricity cost 6.52 cents per kW-hr.

TABLE 17. - Estimated annual operating costs for greenhouses, Kobuk site

Item	Description	Absentee owner	Owner-operated
Direct costs:			
Electricity..........	50,000 kW-hr at 6.52 cents/kW-hr...	$3,300	$3,300
Maintenance..........	Supplies and parts.................	2,400	2,400
Plant food...........	4,000 lb at 70 cents/lb............	2,800	2,800
Miscellaneous........	Seed, peat, disinfectant...........	700	700
Labor................	16 man-hr/day x 365 days x $7.50/hr	43,800	[1]34,700
Supervision..........	General operation responsibility...	24,000	-
Fringe benefits......	27% of salaries....................	18,300	[2]3,600
Geothermal water.....	175 gpm x 60 min/hr x 8,300 hr/yr x 20 cents/M gal.	17,400	17,400
Vehicle operation....	30,000 mi/yr x 19 cents/mi.........	5,700	5,700
Total direct costs	-	118,400	71,600
Indirect costs.........	10% of direct costs................	11,800	7,200
Fixed costs:			
Taxes, insurance.....	2% of investment value.............	8,600	[3]8,600
Depreciation:			
Plant..............	5% per year........................	21,100	5,400
Mobile equipment...	20% per year.......................	2,000	2,000
Total fixed costs.	-	31,700	16,000
Grand total.......	-	161,900	94,800

[1]Wages chosen to be $35,700.
[2]Includes workmen's compensation and social security payments only.
[3]2% of replacement value, turnkey basis.

The cost to produce 140,000 pounds of agricultural products was $1.66 per pound by the contracted units and 80 cents per pound by the owner-operator units (table 18). This compared with a retail price of $1.29 per pound in March 1974 for Bethel, Alaska, a remote village (13). These costs include a 12% DCF rate of return on investment.

TABLE 18. - Financial analyses for greenhouses, Kobuk site (12% DCF, 20-yr life)

	Turnkey	Owner-operated
Total original capital requirements	$472,500	$141,300
5-year equipment cost at present-worth value	5,700	5,700
10-year equipment cost at present-worth value	3,200	3,200
15-year equipment cost at present-worth value	1,800	1,800
Total capital requirements	483,200	152,000
Positive cash flow[1]	64,700	20,400
Less depreciation	23,100	7,400
Net profit	41,600	13,000
Sales revenues	232,500	112,100
Less operating costs	161,900	94,800
Taxable income	70,600	17,300
Less Federal and States taxes[2]	29,000	4,300
Net profit	41,600	13,000

Value of produce in turnkey operation = $232,500/yr ÷ 140,000 lb/yr = $1.66/lb.

Value of produce in owner-operated operation = $112,100/yr ÷ 140,000 lb/yr = $0.80/lb.

[1] Derived by dividing total capital costs by the present-worth factor of 7.469.
[2] 25% of first $25,000 of taxable income + 50% of all in excess of $25,000.

Unalaska Site

Greenhouses in the Unalaska area would be located next to the power generators 16 miles via the proposed gravel road between the generators and the town. The produce could be marketed at Unalaska to personnel associated with the proposed mine, and possibly to nearby villages.

Construction costs were estimated at $406,800 if a contractor were hired, or $130,900 if the owner-operators built the units themselves (table 19). The estimated cost per square foot for the contracted units was $24.00 versus $6.70 for the owner-operated units, excluding contingencies, interest during construction, vehicles, or working capital.

Operating costs for the contracted units were estimated at $144,200 annually versus $80,100 for the owner-operated greenhouses (table 20). Electricity costs 23.38 cents per kW-hr and water consumption averaged 108 gpm for the four greenhouses combined. Labor was assumed to cost $7 per hour for the contracted units and supervision $20,000 per year. The owner-operators were allowed $28,000 in wages and $15,900 in taxable income from the operation, or $43,900 annually.

TABLE 19. - Capital costs for greenhouses, Unalaska site

Item	Number	Description	Turnkey	Owner-constructed
Greenhouse	4	26-ft by 125-ft building, domed fiberglass roof, heating unit, at $24/sq ft, installed.	$312,000	-
Greenhouse	4	26-ft by 125-ft building, domed fiberglass roof, heating unit:	-	
		Materials, including transportation to the site.	-	$73,000
		Labor cost for 2 men to live for 6 months	-	14,000
Vehicles	2	3/4-ton pickups	9,000	9,000
Subtotal	-	-	321,000	96,000
Contingency	-	-	32,100	9,600
Subtotal	-	-	353,100	105,600
Interest during construction	-	-	17,700	5,300
Subtotal	-	-	370,800	110,900
Working capital[1]	-	-	36,000	20,000
Total investment	-	-	406,800	130,900

[1] 25% of annual operating cost.

TABLE 20. - Estimated annual operating costs for greenhouses, Unalaska site

Item	Description	Absentee owner	Owner-operated
Direct costs:			
Electricity	40,000 kW-hr at 23.38 cents/kW-hr	$9,400	$9,400
Maintenance	Supplies and parts	2,200	2,200
Plant food	4,000 lb at 65 cents/lb	2,600	2,600
Miscellaneous	Seed, peat, disinfectant	600	600
Labor	16 man-hr/day x 365 days x $7/hr	40,900	[1] 28,000
Supervision	General operation responsibility	20,000	-
Fringe benefits	27% of salaries	16,400	[2] 2,800
Geothermal water	108 gpm x 60 min/hr x 8,300 hr/yr x 20 cents/M gal.	10,800	10,800
Vehicle operation	20,000 mi/yr x 17 cents/mi	3,400	3,400
Total direct costs	-	106,300	59,800
Indirect costs	10% of direct costs	10,600	6,000
Fixed costs:			
Taxes, insurance	2% of investment value	7,400	[3] 7,400
Depreciation:			
Plant	5% per year	18,100	5,100
Mobile equipment	20% per year	1,800	1,800
Total fixed costs	-	27,300	14,300
Grand total	-	144,200	80,100

[1] Wages chosen to be $28,000.
[2] Includes workmen's compensation and social security payments only.
[3] 2% of replacement value, turnkey basis.

The cost of produce from the contracted facilities was $1.45 per pound versus 69 cents per pound from the owner-operated units. Both figures include a 12% DCF rate of return on investment (table 21). The price of tomatoes in March 1974 was $1.22 per pound in Nome, Alaska, a remote town on the Bering Sea (13).

TABLE 21. - Financial analyses for greenhouses, Unalaska site (12% DCF, 20-yr life)

	Turnkey	Owner-operated
Total original capital requirements	$406,800	$130,900
5-year equipment costs at present-worth value	5,100	5,100
10-year equipment costs at present-worth value	2,900	2,900
15-year equipment costs at present-worth value	1,600	1,600
Total capital requirements	416,400	140,500
Positive cash flow[1]	55,800	18,800
Less depreciation	19,900	6,900
Net profit	35,900	11,900
Sales revenues	[2] 203,500	[3] 96,000
Less operating costs	144,200	80,100
Taxable income	59,300	15,900
Less Federal and State taxes[2]	23,400	4,000
Net profit	35,900	11,900

Value of produce in turnkey operation = $203,500/yr ÷ 140,000 lb/yr = $1.45/lb.

Value of produce in owner-operated operation = $96,000/yr ÷ 140,000 lb/yr = $0.69/lb.

[1] Derived by dividing total capital costs by the present-worth factor of 7.469.

[2] 25% of first $25,000 of taxable income + 50% of all in excess of $25,000.

Stikine River Site

Greenhouses would be located near the geothermal site on the Stikine River approximately 50 miles from either Petersburg or Wrangell via a proposed Alaska State highway (fig. 6). Both towns would provide the marketing area for the agricultural produce.

Total contracted construction costs for greenhouses in this area were estimated at $325,400 versus $119,300 for units constructed by owner-operators (table 22). The basic cost of the four greenhouses was $19 per square foot using a contractor, or $6.21 with the owner-operators doing the construction, excluding contingencies, vehicles, interest during construction, and working capital.

TABLE 22. - Capital costs for greenhouses, Stikine River site

Item	Number	Description	Turnkey	Owner-constructed
Greenhouse	4	26-ft by 125-ft building, domed fiberglass roof, heating unit, at $19/sq ft, installed.	$247,000	-
Greenhouse	4	26-ft by 125-ft building, domed fiberglass roof, heating unit:		
		Materials, including transportation to the site.	-	$68,800
		Labor cost for 2 men to live for 6 months	-	12,000
Vehicles	2	3/4-ton pickups	8,000	8,000
Subtotal	-	-	255,000	88,800
Contingency	-	-	25,500	8,900
Subtotal	-	-	280,500	97,700
Interest during construction	-	-	14,000	4,900
Subtotal for depreciation.	-	-	294,500	102,600
Working capital[1]	-	-	30,900	16,700
Total investment	-	-	325,400	119,300

[1] 25% of annual operating cost.

Operating costs were $123,500 annually with the contracted units versus $66,700 with the owner-operators (table 23). With 140,000 pounds of produce each year, the cost of produce would be 88 cents and 48 cents per pound for the contracted and owner-operated ventures, respectively. Electricity was estimated to cost 6.23 cents per kW-hr and geothermal water 20 cents per thousand gallons at an average consumption of 94 gpm for the four greenhouses combined. Wages for the contracted units were estimated to cost $6.50 per hour and supervision $20,000 per year. The wages plus the taxable income for the owner-operators were $40,000 annually.

The cost of the produce was $1.20 per pound from the contractor facilities versus 58 cents per pound from the owner-operator greenhouses, including a 12% DCF rate of return on investment (table 24). This compares with a March 1974 price of 63 cents per pound for tomatoes in Petersburg (13).

TABLE 23. - Estimated annual operating costs for greenhouses, Stikine River site

Item	Description	Absentee owner	Owner-operated
Direct costs:			
Electricity..........	40,000 kW-hr at 6.23 cents/kW-hr....	$2,500	$2,500
Maintenance..........	Supplies and parts..................	2,000	2,000
Plant food...........	4,000 lb at 60 cents/lb.............	2,400	2,400
Miscellaneous........	Seed, peat, disinfectant............	500	500
Labor................	16 man-hr/day X 365 days X $6.50/hr.	38,000	[1]25,600
Supervision..........	General operation responsibility....	18,000	-
Fringe benefits......	27% of salaries.....................	15,100	[2]2,600
Geothermal water.....	94 gpm X 60 min/hr X 8,300 hr/yr X 20 cents/M gal.	9,400	9,400
Vehicle operation....	30,000 mi/yr x 15 cents/mi..........	4,500	4,500
Total direct costs	-	92,400	49,500
Indirect costs.........	10% of direct costs.................	9,200	5,000
Fixed costs:			
Taxes, insurance.....	2% of investment value..............	5,900	[3]5,900
Depreciation:			
Plant..............	5% per year.........................	14,400	4,700
Mobile equipment...	20% per year........................	1,600	1,600
Total fixed costs.	-	21,900	12,200
Grand total.......	-	123,500	66,700

[1]Wages chosen to be $25,600.
[2]Includes workmen's compensation and social security payments only.
[3]2% of replacement value, turnkey basis.

TABLE 24. - Financial analyses for greenhouses, Stikine River site (12% DCF, 20-yr life)

	Turnkey	Owner-operated
Total original capital requirements......................	$325,400	$119,300
5-year equipment costs at present-worth value.............	4,500	4,500
10-year equipment costs at present-worth value............	2,600	2,600
15-year equipment costs at present-worth value............	1,500	1,500
Total capital requirements................................	334,000	127,900
Positive cash flow[1]	44,700	17,100
Less depreciation...	16,000	6,300
Net profit..	28,700	10,800
Sales revenues..	168,400	81,100
Less operating costs......................................	123,500	66,700
Taxable income..	44,900	14,400
Less Federal and State taxes[2]...........................	16,200	3,600
Net profit..	28,700	10,800

Value of produce in turnkey operation = $168,400/yr ÷ 140,000 lb/yr = $1.20/lb.

Value of produce in owner-operated operation = $81,100/yr ÷ 140,000 lb/yr = $0.58/lb.

[1]Derived by dividing total capital costs by the present-worth factor of 7.469.
[2]25% of first $25,000 of taxable income + 50% of all in excess of $25,000.

CONCLUSIONS

This report investigated the potential for mineral development that might exist should geothermal energy sources near known mineral deposits be developed. This report was orientated toward the prospects of generating power from geothermal reservoirs. Assuming the mining venture was viable, secondary uses of geothermal water for space heating and agriculture were investigated to see if their use might be economical. Sites near Kobuk in northwestern Alaska, Unalaska in southwestern Alaska, and the Stikine River in southeastern Alaska were chosen.

The cost of electricity generated by the geothermal powerplant was compared with that of the diesel powerplant. At all three locations, the capital cost to install a geothermal plant exceeded the cost of the diesel plant. When a 12% DCF rate of return was included in the costs, the geothermal power was cheaper at the Kobuk and Stikine River sites; the diesel power was cheaper at Unalaska. The large initial capital expenditures and the uncertainty of locating the required volume of sufficiently hot water were definite negative aspects of geothermal power development. Diesel-power generation suffered from the uncertainty of future fuel prices and supplies.

Space heating was found to be too expensive at any of the study sites owing to the distance from the geothermal source to the point of use. Most sites heated by geothermal water in other areas of the world are located less than 30 miles from the geothermal source and use high volumes of hot water. At the Kobuk site, 80 miles from the assumed geothermal source, a sufficient market would develop but the distance was too great.

The feasibility of utilizing the waste water from power generation for agriculture was investigated for each of the three power sites. Two methods of ownership and operation were studied: the absentee owner and the owner-operator. The absentee owner had his plant constructed and operated for him; the owner-operator was assumed to consist of two families who built and operated the greenhouses themselves. The capital costs of the owner-operated installations were approximately one-third the costs of the contracted units. Both operating costs and capital costs, including a 12% DCF rate of return, were about one-half the costs required by the absentee owners. The price required for produce grown at the three sites by the owner-operators was attractive compared with retail prices for produce at other remote villages or towns.

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